

(19) World Intellectual Property  
Organization  
International Bureau



(43) International Publication Date  
30 June 2005 (30.06.2005)

PCT

(10) International Publication Number  
**WO 2005/059654 A1**

(51) International Patent Classification<sup>7</sup>: **G03F 7/20**

(21) International Application Number:  
PCT/EP2004/014219

(22) International Filing Date:  
14 December 2004 (14.12.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
10/734,623 15 December 2003 (15.12.2003) US  
60/530,623 19 December 2003 (19.12.2003) US  
60/544,967 13 February 2004 (13.02.2004) US  
60/568,006 4 May 2004 (04.05.2004) US  
60/591,775 27 July 2004 (27.07.2004) US  
60/592,208 29 July 2004 (29.07.2004) US  
60/612,823 24 September 2004 (24.09.2004) US

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

(71) Applicant (for all designated States except US): **CARL ZEISS SMT AG** [DE/DE]; Carl-Zeiss-Str. 22, 73447 Oberkochen (DE).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **SHAFER, David** [US/US]; 56 Drake Lane, Fairfield, CT 06430 (US). **BEDER, Susanne** [DE/DE]; Brandenburger Strasse 59, 73431 Aalen (DE). **SCHUSTER, Karl-Heinz** [DE/DE]; Rechbergstrasse 24, 89551 Königsbrunn (DE).

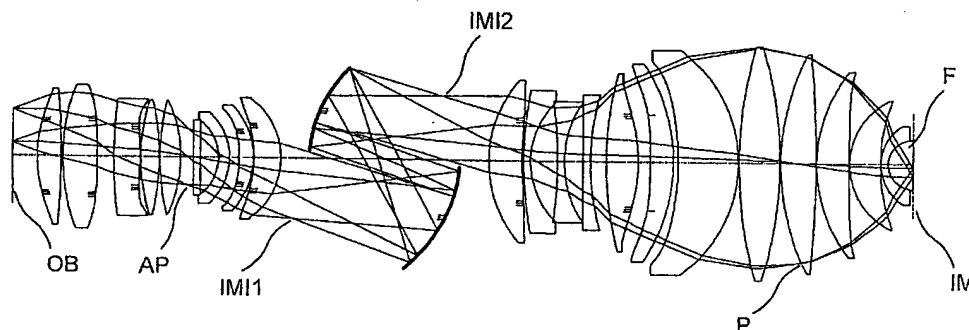
(74) Agent: **MÜLLER-RISSMANN, Werner**; Carl Zeiss AG, Patentabteilung, 73446 Oberkochen (DE).

#### Declarations under Rule 4.17:

— as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW, ARIPO patent (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT,

[Continued on next page]

(54) Title: OBJECTIVE AS A MICROLITHOGRAPHY PROJECTION OBJECTIVE WITH AT LEAST ONE LIQUID LENS



(57) Abstract: The invention relates to an objective designed as a microlithography projection objective for an operating wavelength. The objective has a greatest adjustable image-side numerical aperture NA, at least one first lens made from a solid transparent body, in particular glass or crystal, with a refractive index  $n_L$  and at least one liquid lens (F) made from a transparent liquid, with a refractive index  $n_F$ . At the operating wavelength the first lens has the greatest refractive index  $n_L$  of all solid lenses of the objective, the refractive index  $n_F$  of the at least one liquid lens (F) is bigger than the refractive index  $n_L$  of the first lens and the value of the numerical aperture NA is bigger than 1.



BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)

- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations
- of inventorship (Rule 4.17(iv)) for US only

**Published:**

- with international search report

- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

OBJECTIVE AS A MICROLITHOGRAPHY PROJECTION OBJECTIVE  
WITH AT LEAST ONE LIQUID LENS

BACKGROUND OF THE INVENTION

Field of the invention

The complete disclosure of US Application Ser. No. 10/734,623 filed on December 15, 2003, International Application No. PCT/EP2004/005816 filed on May 28 2004, US Application Ser. No. 60/530,623 filed on December 19, 2003, US Application Ser. No. 60/530,978 filed on December 22, 2003, European Application No. 03256499.9 filed on October 15, 2003, US Application Ser. No. 60/544,967 filed on February 13, 2004, US Application Ser. No. 60/592,208 filed on July 29, 2004, US Application Ser. No. 60/568,006 filed on May 4, 2004, US Application Ser. No. 60/591,775 filed on July 27, 2004 and US Application Ser. No. 60/612,823 filed on September 24, 2004 is hereby incorporated.

The invention relates to an objective designed as a microlithography projection objective. The objective according to the invention comprises at least one liquid lens made from a transparent liquid.

Description of the Related Art

Microlithography projection objectives of multivarious design are known.

- 2 -

In all imaging systems, the smallest resolvable structural width is proportional to the numerical aperture NA at the image plane.

- 5 This, in turn, is proportional to the angle of incidence and the refractive index  $n_i$  of the medium through which the light falls onto the image plane.

By contrast with so-called dry objectives with gas  
10 (air,  $N_2$ , He and the like) or a vacuum with a refractive index of approximately 1.0, a material, in particular a liquid, with a substantially higher refractive index is used as this medium in immersion systems.

- 15 For example, as far as is known for the wavelength 193 nm water has a refractive index  $n_{H_2O} = 1.44$ .

High-index lenses with a refractive index much higher than 1.6 have been used in microlithography at  
20 wavelengths of greater than 365 nm, but they become incapable of use at the wavelengths of practical relevance such as 248 nm, 195 nm, 157 nm, since they are not sufficiently transparent, and so on. Lenses made from sapphire have a high refractive index but are  
25 birefringent, and this must be compensated in a complicated way and with limited success.

#### SUMMARY OF THE INVENTION

- 30 The inventors have recognized that, furthermore, the possible image-side numerical aperture NA is limited by the refractive index of the curved optical element next to the image plane.

- 3 -

Such an element can be provided as a liquid lens that can also serve simultaneously as immersion liquid, specifically with or without a plane-parallel separation plate. However, if the refractive index  $n_F$  thereof lags behind the refractive index  $n_L$  of the solid lenses used in the objective, the achievable NA remains still smaller,  $NA < n_F$ .

10 The difference is significant in the case of a 193 nm objective with lenses made from fused silica with  $n_L = 1.56$  and with water as an immersion and a liquid lens with  $n_F = 1.44$ .

15 According to the invention, use is made in the objective of at least one liquid lens whose refractive index  $n_F$  is greater than the refractive index  $n_L$  of each solid lens in the objective. The first lens in the meaning of Claim 1 is the lens, arranged at any desired  
20 location in the objective, made from the highest-index solid lens material which is used in the objective. As also in the embodiments shown, all the lenses - except for the liquid lens or lenses - consist in many cases of the same solid material.

25 With respect to lenses made from fused silica or calcium fluoride, which are established for microlithography projection objectives with the operating wavelengths of 248 nm, 193 nm, 157 nm,  
30 liquids with, for example,  $n_F = 1.6$ ,  $n_F = 1.65$  or  $n_F = 1.8$  are suitable.

- 4 -

There is a corresponding result for other lens materials known for the deep UV (DUV) and vacuum UV, such as fluoride crystals  $\text{BaF}_2$ ,  $\text{SrF}_2$ ,  $\text{LiF}$ ,  $\text{NaF}$  and others.

5

Although there are many developments of immersion liquids for applications in microlithography, it is clear at least in principle that  $\text{H}_2\text{SO}_4$  (sulfuric acid),  $\text{H}_3\text{PO}_4$  (phosphoric acid) and their solutions in  $\text{H}_2\text{O}$  (water) yield adjustable refractive indices of 1.5 - 1.8 at 193 nm in conjunction with suitable transmission. In addition, the corrosive action of these substances is substantially reduced with the aid of substitution of heavy isotopes, in particular deuterium. This is described inter alia in US Application Ser. No. 60/568,006.

Corrosion protection layers can be provided on the solid optical elements. This is disclosed inter alia in US Application Ser. No. 60/530,623.

Accordingly, an objective having the features of Claim 1 has surprisingly been found to be particularly advantageous. A microlithography projection objective with an image-side numerical aperture NA greater than 1, which is not accessible for a dry objective, is substantially relieved and extended as regards the possibilities for its optical design and correction when use is made of a liquid lens with a refractive index greater than the refractive index of the solid lenses. In the case of lenses made from different materials, the largest refractive index of all these lenses is exceeded. A plane-parallel plate, in

- 5 -

particular an end plate made from sapphire, for example, may have a higher refractive index, in this case.

5 Objectives are usually corrected for specific operating wavelengths and can be operated reasonably only at these wavelengths. The refractive indices of all materials vary with wavelength, and it is always the values for the operating wavelength which are used as a  
10 basis here. Other wavelengths can traverse the objective, for example for the purposes of measurement.

It has surprisingly been found that on the basis of the invention it is possible to design objectives with an  
15 NA greater than the refractive index  $n_L$  of every solid lens. This is also reflected in Claim 2.

The liquid lens can be an immersion at the same time, that is to say it can be in contact to the object to be  
20 exposed. Alternatively, it is possible for an optical element made from a solid transparent body, in particular an end plate, to be arranged there between.

The liquids of the liquid lens and of the immersion at  
25 the object can then be adapted to various conditions such as:

- in the case of the immersion:
  - rapid movement for step-and-scan
  - contact with materials of the wafer such as  
30 resist
  - contact with air
  - cleaning requirements for wafer processing after exposure

- 6 -

- in the case of the liquid lens:
  - contact with material of the adjacent solid lens

5 and be selected, accordingly.

Since the refractive indices  $n_F$  of the liquid lens and  $n_I$  of the immersion are lower bounds for the achievable NA, it is natural to prefer that  $n_F = n_I$ .

10

The effect of increasing the accessible NA caused by the liquid lens with high refractive index  $n_F$  becomes greatest when said lens is the last curved element on the image side.

15

Substantially hemispherical last lenses have proved in this case to be advantageous, since then the angle of incidence of the light varies relatively slightly over the lens surface and remains close to the normal to the curved surface. The critical angle of total reflection is thus effectively avoided.

20

Intermediate images in the objective are a measure by which the lens diameters can be kept small. The availability and the price of lens material and of finish-machined lenses in a quality suitable for microlithography projection objectives are very substantially relieved at lower diameters.

25

30 It is therefore to be pointed out that, otherwise than in the US classification 359/642 defined for LENS, here it is precisely also optical systems with an intermediate image, even several thereof, that are

- 7 -

designated as an objective. Designs of objectives suitable for the invention are inter alia disclosed in US Application Ser. No. 60/544,967, US Application Ser. No. 60/592,208 and US Application Ser. No. 60/591,775.

5

The field flattening is a central problem with such an objective, being equivalent to a minimization of the Petzval sum.

10 Primarily for this purpose, but also for color correction (achromatization), a design as a catadioptric system comprising at least one curved mirror in addition to the lenses is advantageous. A combination of a negative lens and a concave mirror is  
15 particularly effective for color correction. Further possibilities for color correction are disclosed in US Application Ser. No. 60/530,978. Catadioptric systems frequently have folding mirrors, thereby permitting the light beams running to a mirror to be separated from  
20 those returning therefrom. Such systems are also described and covered here.

However, all surfaces of the optical system are effective for correction when all mirrors are curved.  
25 This is possible, in particular, with an even number, especially 2, of curved mirrors. It is also possible in this case for the entire objective to be constructed along a common axis of symmetry in relation to which all the mirror and lens surfaces exhibit a rotationally  
30 symmetrical shape where light passes through. However, there is asymmetric edging in the region of the mirrors and, if appropriate, adjacent lenses. Adjustment and vibration resistance as well as installation space

- 8 -

requirements of the objective profit from the common axis of symmetry.

It is favorable in this case if the objective comprises  
5 an image-side objective part arranged at the image-side end of the objective and an intermediate objective part preceding the image-side objective part with respect of the direction of the light moving from the object-side end to the image-side end of the objective. If not  
10 defined otherwise, this direction is the reference whenever a position of a component of the objective is defined. The intermediate objective part is containing mirrors and may be designed catoptrically as, for example, in fig. 1 - fig. 3, or catadioptrically as in  
15 the other embodiments. The image-side objective part, which is purely refractive, is providing the extreme aperture and comprises the liquid lens.

It did surprisingly turn out that this image side  
20 objective part advantageously has its pupil in the region of the beam path which is convergent in relation to the image plane, or, as described in Claim 11, that said pupil is located between the lens of the greatest diameter used and the image plane.

25 In this region, the strong positive refractive power which is required in order to produce the large angles of incidence at the image plane in accordance with the high NA is expediently distributed over a plurality of  
30 positive meniscus lenses which are concave on the image side. Both chromatic aberrations and contributions to the Petzval sum are thereby reduced.

- 9 -

The inventors have established that the solid lens preceding the liquid lens according to the invention and defining the object-side surface of the liquid lens should be a meniscus lens whose center thickness  
5 (THICKNESS in accordance with the tables) is smaller than the difference of the radii of curvature (RADIUS) of the two lens surfaces. Such a meniscus lens having negative refractive power in the paraxial region makes a transition in part to an action of positive  
10 refractive power in the outer region where beams strike more steeply, that is from further outside, than the normal to the surface.

It is advantageous when the objective comprises an  
15 object-side objective part being arranged at the object-side end of the objective and producing an intermediate image on the object side of the intermediate objective part.

20 This permits, inter alia, greater freedom in configuring the passage of the light bundles next to the mirrors, and yields an additional diaphragm location which can well be situated in an air space and is therefore well suited as a stop-down aperture  
25 diaphragm.

It is to be seen in the embodiments that it is advantageous to provide lenses of low refractive power with a strongly modulated aspheric shape preceding this  
30 diaphragm plane and to provide a strongly curved meniscus lens subsequent to this diaphragm plane, the meniscus lens being concave on the diaphragm side.

- 10 -

It is clear that such high-aperture projection objectives for microlithography of very high resolution require intensive use of aspherics, since essential parameters for image correction are thereby provided.

5

Deliberate use is also made in the exemplary embodiments of very strong aspherics and those whose deviation from the spherical shape does not exhibit a monotonic profile over the distance from the optical axis.

10

As already mentioned, such aspherics are particularly advantageous in the object-side objective part.

15 It emerges in addition that in the image-side objective part some positive lenses yield particularly suitable arrangements of strong aspherics. These positive lenses are situated in the region of the steeply rising light bundle diameter between the negative lenses arranged  
20 near the intermediate image and the belly of the light bundle at the lens with the maximum of the diameter of the light bundle passing through.

The embodiments presented are partly of an experimental  
25 nature. However, to the person skilled in the art who compares these with similar design solutions known to him and derives modifications therefrom they yield clear-cut teachings from which he is able to modify designs of objectives.

30

The various designs of the individual embodiments make this clear, and can, of course, also be combined with

- 11 -

one another and with other known designs in the meaning of the invention.

The exemplary embodiments are explained in more detail  
5 with the aid of the drawings, in which

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 to 6 respectively show a meridian section of an  
10 embodiment of an objective according to the invention.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

In Fig. 1 to 6 marginal and principal rays are depicted  
15 for the object points nearest and furthest from the axis. Aspheric surfaces are marked twice with 3 lines at the contour.

The optical axis or the axis of symmetry of the  
20 curvatures of the surfaces is marked by dots and dashes.

In each case OB denotes the object plane. This corresponds to the surface (SURF) 0 in the tables. IM  
25 denotes the image plane and corresponds in each case to the surface of the highest number in the tables.

F respectively denotes the liquid lens according to the  
invention.

30

EP denotes an optional end plate.

IMI1 and IMI2 are the intermediate images.

- 12 -

AP denotes the position of the system aperture at which an adjustable diaphragm can be arranged and will also be referred to as diaphragm plane.

5

P denotes the pupil in an image-side objective part.

All embodiments shown are designed for the operating wavelength 193.4 nm (ArF Excimer Laser) and reduce by  
10 1:4 - without limiting the invention thereto.

Tables 1a to 6a respectively give the design data for the drawing of the same number. Tables 1b to 6b respectively specify the aspheric data of the aspheric  
15 lens and mirror surfaces, which are identified in the drawings by three primes. The illustration is made using the Optik-Design-Software CODE V<sup>TM</sup> from Optical Research Associates and corresponds to their conventions.

20

In each embodiment shown in fig. 1 to 6 the objective comprise an object-side objective part, an image-side objective part and an intermediate objective part. The object-side objective part is situated at the object-  
25 side end of the objective. The image-side objective part is situated at the image-side end of the objective. The intermediate objective part is situated between the object-side objective part and the image-side objective part. In the embodiments the object-side  
30 objective part and the image side objective part are purely reflective. The intermediate objective part is catoptric or catadioptric.

- 13 -

In the embodiments of fig. 1 to fig. 3 the value of the numerical aperture  $NA = 1.4$ . The liquid of the lens F and the immersion have the same refractive index  $n_F = n_I = 1.65$ . The material of the solid lenses is fused silica with an index of refraction  $n_L = 1.56$ .

The distance from the object plane OB to the image IM is 1250 mm and thereby a common value.

10 The image field is 26 mm x 5.5 mm, decentered by 4.66 mm. However, the correction state yields an RMS wave front error of this image field of approximately 10-20 per mil of the operating wavelength.

15 The lenses of the object-side objective part and the image side objective part are rotationally symmetrical in relation to a common axis of symmetry, with the two mirrors of the catoptric version of the intermediate objective part certainly being curved in an axially symmetrical fashion, but being edged asymmetrically.

The design of the objective will now be described in more detail with respect to the embodiment of fig. 1. Most of the features are also present at the  
25 embodiments of fig. 2 to 6, but will only be explained in some detail with respect to fig. 1.

The object-side objective part comprises an accessible diaphragm plane AP with the stop-down system diaphragm.  
30 Preceding the diaphragm plane AP there is a particularly strongly modulated aspheric (surface 7 of table 1a/b). Subsequent to the diaphragm plane AP there

- 14 -

is a meniscus lens which is concave on the side of the diaphragm plane AP (surfaces 15, 16 in table 1a).

The intermediate objective part is designed catoptrically and comprises two concave mirrors (surfaces 23, 24 in table 1a).

The image-side objective part subsequent to the second intermediate image IMI2 - the intermediate images are not corrected and do not form an image plane - begins with a positive lens group of single-lens design, forms a waist with a number of negative lenses, and has a positive lens group with many members which forms a massive belly.

Strongly modulated aspherics (inter alia, surface 36 in table 1a/b) are significant in the initial region of the positive lens group where the diameter of the light bundle and of the lenses are increasing. The middle of the belly is formed by the lens of greatest diameter (surface 41/42 in table 1a/b, height (SEMIDIAM, half lens diameter) 160 mm). The production of lithographic projection objectives is very economical with this lens diameter. The pupil P of the image-side objective part is, in a fashion typical of the objectives according to the invention, following this largest lens in the convergent beam path.

In the embodiment of fig. 1, the liquid lens F is formed between the surface 50 and the image plane IM (surface 52) and is at the same time the immersion. It is virtually hemispherical given the radius 34.6 mm and the thickness  $30.1 + 3.0 = 33.1$  mm. The ratio of radius

- 15 -

to thickness is 1.05. The adjacent last fused silica lens is in this case a meniscus lens whose thickness of 10 mm is substantially smaller than the difference of the radii 66 mm - 34 mm (surfaces 49/50).

5

In the embodiment of fig. 2, once again the liquid lens F is at the same time likewise immersion. However, it is substantially flatter than the liquid lens F of fig. 1. Only in combination with the last fused silica lens, 10 the liquid lens F forms an approximately hemispherical member.

Using a rather flat liquid lens F makes the exchange of the liquid simpler.

15

It has been established that a plane-parallel plate which separates the liquid lens F and the immersion is not critical for the optical function. This holds in particular when the refractive index of the plan-parallel plate is greater than the refractive indices  $n_F$  20 of the liquid lens F and  $n_i$  of the immersion.

Starting from the embodiment of fig. 1, fig. 3 shows an embodiment with such an end plate EP of refractive 25 index  $n_{EP} = 1.80$ . By adapting the thickness, it can easily be exchanged for a plate made from sapphire with  $n_{EP} = 1.92$ .

In the embodiment of fig. 4 (table 4a/b) a catadioptric 30 design is used for the intermediate objective part.

- 16 -

Given the same NA,  $n_F$ ,  $n_L$  as the preceding embodiments, the image field is somewhat deviant with 22 x 5.2 mm and greater decentering of 5.753 mm.

5 In this embodiment two planar folding mirrors FM1 (surface 21) and FM2 (surface 31) are used as geometric beam splitters. Provided in a lateral arrangement are a concave mirror - surface 26 in table 4a/b - and lenses of negative refractive power through which the light  
10 passes twice. The surfaces 22-25 of these lenses are thus present once more specularly as 27 to 30 in table 4a/b, since they refract the light twice.

The high-index liquid lens F is also advantageously  
15 used with this quite different approach to the design of the microlithographic projection objective. In a way similar to fig. 1, it is designed here as "immersion lens", touching the object, between the surfaces 63 and 65.

20 The two embodiments of fig. 5 and fig. 6 for the first time exhibit objectives with the numerical aperture NA = 1.6 being greater than the refractive index  $n_L$  of the solid lenses used. The solid lenses are made from fused silica with  $n_L = 1.56$ . The refractive index of the  
25 liquid lens F is  $n_F = 1.80$ . Also these embodiments are corrected much better than in a diffraction-limited fashion, their image field being 20 mm x 4 mm at a decentering of 4.375 mm. The RMS wavefront error is  
30 below a tenth of the operating wavelength 193.4 nm.

Here, as well, the object-side objective part is purely refractive. It includes the accessible and stop-down

- 17 -

diaphragm plane AP and strong aspherics preceding the diaphragm plane AP. Here these aspherics are two lenses of lesser refractive power but stronger modulation of the aspheric shape deviation, surfaces 5 and 8 in table 5a/b. Arranged subsequent to these aspherics is a likewise strongly curved meniscus lens, surfaces 10, 11 in table 5a/6.

The intermediate objective part is once again a prolate catadioptric objective with two concave mirrors, similar to fig. 1-3, but now with a positive field lens (surfaces 20, 21 in table 5a) preceding the second intermediate image IMI2.

The positive field lens replaces the positive first lens group present in fig. 1-3 in the image-side objective part.

The image-side objective part thus begins with a negative lens group and forms a belly with a multilens positive lens group. In the embodiment of fig. 5 the greatest lens diameter is reached with 165 mm at the lenses 30/31 and 32/33 as can be seen in table 5a. A plurality of positive meniscus lenses which are concave in relation to the image plane IM is arranged subsequent to these lenses. The pupil P of the image-side objective part lies in the region of these meniscus lenses. The last fused silica lens (surfaces 40, 41 of table 5a) on the image side is once again of negative refractive power in the paraxial region. This lens is formed as a meniscus lens with a concave surface on the image side whose thickness is 8.9 mm and

- 18 -

thus smaller than the difference of the radii  $58.8 \text{ mm} - 37.8 \text{ mm} = 21 \text{ mm}$ .

In the embodiment of fig. 5, the liquid lens F is  
5 immersion at the same time, and thus abuts the image  
plane IM and the object, which is arranged there in  
order to exposed. This object can be, for example, a  
wafer. The radius of the spherical surface 41 is  $37.8$   
mm and thus smaller than the thickness of  $45.8$  mm.

10

The sine of the angle of incidence is smaller than  $0.89$   
at all surfaces. The catadioptric intermediate  
objective part is enlarging. The sines of the angles of  
incidence at the concave mirrors are below  $0.45$ .

15

The embodiment of fig. 6 and table 6a/b comprise a  $3.0$   
mm thick end plate EP made from sapphire. The liquid  
lens F is now formed between the surfaces 42, 43 of  
table 6a. Their thickness is  $40.2$  mm, the radius is  
20  $38.1$  mm. The thickness is thus  $105\%$  of the radius.

It has thus been shown that liquid lenses F of high  
refractive index permit the design of high-quality  
projection objectives with extreme numerical apertures.

25

Multivarious approaches and instructions are thus given  
to the person skilled in the art in order to use this  
teaching for further developing different kinds of  
known approaches in designing objectives.

30

- 19 -

Table 1a

| SURF    | RADIUS       | THICKNESS   | MATERIAL | INDEX      | SEMIDIAM. |
|---------|--------------|-------------|----------|------------|-----------|
| 0 = OB  | $\infty$     | 35.000000   |          | 1.00030168 | 66.000    |
| 1       | $\infty$     | 0.100881    |          | 1.00030168 | 77.003    |
| 2       | 173.279980   | 34.026411   | SIO2V    | 1.56078570 | 90.000    |
| 3       | -1081.359892 | 2.602590    |          | 1.00029966 | 90.000    |
| 4       | 284.316798   | 47.383982   | SIO2V    | 1.56078570 | 95.000    |
| 5       | -1674.306964 | 22.855576   |          | 1.00029966 | 95.000    |
| 6       | 577.261196   | 36.645573   | SIO2V    | 1.56078570 | 76.354    |
| 7       | -314.377359  | 0.999980    |          | 1.00029966 | 73.677    |
| 8       | 290.150309   | 25.000000   | SIO2V    | 1.56078570 | 75.000    |
| 9       | -348.828624  | 1.000000    |          | 1.00029966 | 75.000    |
| 10      | 357.767685   | 29.107951   | SIO2V    | 1.56078570 | 75.000    |
| 11      | -185.316330  | 18.309132   |          | 1.00029966 | 75.000    |
| 12      | $\infty$     | 0.000000    |          | 1.00029966 | 36.370    |
| 13      | $\infty$     | 10.000000   | SIO2V    | 1.56078570 | 44.778    |
| 14      | $\infty$     | 24.909905   |          | 1.00029966 | 47.596    |
| 15      | -65.374870   | 14.999947   | SIO2V    | 1.56078570 | 50.000    |
| 16      | -87.154980   | 13.643080   |          | 1.00029966 | 60.000    |
| 17      | -175.112352  | 18.964687   | SIO2V    | 1.56078570 | 65.000    |
| 18      | -111.646867  | 1.049880    |          | 1.00029966 | 70.000    |
| 19      | -155.839260  | 37.603622   | SIO2V    | 1.56078570 | 80.000    |
| 20      | -102.943508  | 0.099910    |          | 1.00029966 | 80.000    |
| 21      | $\infty$     | 40.000000   |          | 1.00029966 | 90.389    |
| 22      | $\infty$     | 209.622700  |          | 1.00029966 | 92.498    |
| 23      | -166.402525  | -209.622700 | REFL     | 1.00029966 | 150.000   |
| 24      | 173.713446   | 209.622700  | REFL     | 1.00029966 | 125.000   |
| 25      | $\infty$     | 40.000000   |          | 1.00029966 | 99.138    |
| 26      | $\infty$     | 0.100021    |          | 1.00029966 | 105.283   |
| 27      | 174.736655   | 46.035435   | SIO2V    | 1.56078570 | 110.000   |
| 28      | 369.899337   | 2.484896    |          | 1.00029966 | 105.000   |
| 29      | 511.775400   | 10.000000   | SIO2V    | 1.56078570 | 95.000    |
| 30      | 117.498299   | 37.368783   |          | 1.00029966 | 80.000    |
| 31      | -690.607305  | 10.000000   | SIO2V    | 1.56078570 | 80.000    |
| 32      | 153.845418   | 25.455370   |          | 1.00029966 | 80.000    |
| 33      | 20331.979093 | 10.000000   | SIO2V    | 1.56078570 | 90.000    |
| 34      | 347.272006   | 22.437822   |          | 1.00029966 | 90.000    |
| 35      | 502.344250   | 44.143760   | SIO2V    | 1.56078570 | 120.000   |
| 36      | -231.373663  | 17.400867   |          | 1.00029966 | 120.000   |
| 37      | -837.483770  | 31.483968   | SIO2V    | 1.56078570 | 130.000   |
| 38      | -254.746002  | 6.600316    |          | 1.00029966 | 135.000   |
| 39      | -392.185232  | 82.775939   | SIO2V    | 1.56078570 | 140.000   |
| 40      | -196.513232  | 1.000000    |          | 1.00029966 | 155.000   |
| 41      | 610.397747   | 56.287416   | SIO2V    | 1.56078570 | 160.000   |
| 42      | -556.907407  | 0.999835    |          | 1.00029966 | 160.000   |
| 43      | 296.607308   | 48.957456   | SIO2V    | 1.56078570 | 150.000   |
| 44      | -1578.327293 | 1.000000    |          | 1.00029966 | 150.000   |
| 45      | 216.352446   | 43.826306   | SIO2V    | 1.56078570 | 125.000   |
| 46      | 2322.892305  | 1.000000    |          | 1.00029966 | 125.000   |
| 47      | 101.534703   | 42.624105   | SIO2V    | 1.56078570 | 88.000    |
| 48      | 255.691515   | 0.999893    |          | 1.00029966 | 85.000    |
| 49      | 66.827516    | 10.000000   | SIO2V    | 1.56078570 | 52.000    |
| 50      | 34.581844    | 30.092080   | (F)      | 1.65000000 | 34.000    |
| 51      | $\infty$     | 3.000000    | (F)      | 1.65000000 | 34.000    |
| 52 = IM | $\infty$     |             |          |            | 34.000    |

- 20 -

Table 1b

| ASPHERIC |               | ONSTANTS      |               |               |               |  |  |
|----------|---------------|---------------|---------------|---------------|---------------|--|--|
| SRF      | 2             | 5             | 7             | 17            | 19            |  |  |
| K        | 0             | 0             | 0             | 0             | 0             |  |  |
| C1       | -5.719118e-08 | -1.218375e-07 | 4.192613e-07  | -2.035191e-07 | 6.581837e-08  |  |  |
| C2       | -6.011473e-13 | 9.454546e-12  | 4.225479e-12  | -2.746520e-11 | 1.290762e-11  |  |  |
| C3       | -2.863941e-16 | -1.629731e-15 | 1.483284e-15  | -2.529717e-15 | 6.638127e-16  |  |  |
| C4       | 2.205921e-20  | 1.088963e-19  | 3.420546e-19  | 5.381454e-19  | -2.943367e-19 |  |  |
| C5       | -5.981074e-24 | 8.373344e-24  | -2.828899e-23 | -1.447893e-22 | 3.550178e-24  |  |  |
| C6       | 1.047361e-27  | -1.832764e-27 | -1.680731e-27 | -3.175732e-27 | 6.050767e-28  |  |  |
| C7       | -1.013527e-31 | 1.046373e-31  | 2.906586e-31  | 5.176529e-30  | 4.358568e-31  |  |  |
| C8       | 4.076124e-36  | -1.708389e-36 | -5.252329e-35 | -1.024665e-33 | -4.270946e-35 |  |  |
| SRF      | 23            | 24            | 28            | 36            | 37            |  |  |
| K        | -0.602272     | -0.240254     | 0             | 0             | 0             |  |  |
| C1       | 0.000000e+00  | 0.000000e+00  | -1.628020e-07 | 2.060497e-08  | -7.918942e-08 |  |  |
| C2       | -9.110764e-15 | 3.799619e-15  | 5.004648e-12  | 6.206171e-13  | -7.390346e-13 |  |  |
| C3       | -6.923032e-20 | 1.050462e-19  | 1.238115e-16  | 1.568846e-16  | 1.677228e-16  |  |  |
| C4       | -1.592422e-23 | 2.407529e-23  | 1.345805e-20  | -1.970417e-20 | -6.727857e-21 |  |  |
| C5       | 8.704660e-28  | -2.336605e-27 | -5.722714e-24 | 2.817612e-24  | 6.703292e-25  |  |  |
| C6       | -3.848813e-32 | 2.089863e-31  | 7.429779e-28  | -2.065939e-28 | -1.712552e-29 |  |  |
| C7       | 8.257231e-37  | -8.540536e-36 | -5.390293e-32 | 7.979829e-33  | -9.430098e-34 |  |  |
| C8       | -7.590177e-42 | 1.725784e-40  | 1.988577e-36  | -1.039469e-37 | 4.239222e-38  |  |  |
| SRF      | 39            | 43            | 46            |               |               |  |  |
| K        | 0             | 0             | 0             |               |               |  |  |
| C1       | 5.160606e-09  | -2.788258e-08 | -2.365786e-08 |               |               |  |  |
| C2       | -2.393183e-13 | 4.064341e-13  | 3.640299e-12  |               |               |  |  |
| C3       | -7.204528e-17 | 2.762083e-17  | -1.570433e-16 |               |               |  |  |
| C4       | -1.517240e-22 | -4.172618e-22 | 6.381899e-21  |               |               |  |  |
| C5       | -3.032479e-27 | -3.754486e-27 | -3.770869e-26 |               |               |  |  |
| C6       | 1.227351e-29  | -6.324033e-31 | -1.116749e-29 |               |               |  |  |
| C7       | -8.867490e-34 | 3.185590e-35  | 6.455153e-34  |               |               |  |  |
| C8       | 2.067251e-38  | -4.120762e-40 | -1.076920e-38 |               |               |  |  |

- 21 -

Table 2a

| SURF    | RADIUS       | THICKNESS   | MATERIAL | INDEX      | SEMIDIAM. |
|---------|--------------|-------------|----------|------------|-----------|
| 0 = OB  | $\infty$     | 35.000000   |          | 1.00030168 | 66.000    |
| 1       | $\infty$     | 1.166644    |          | 1.00030168 | 77.003    |
| 2       | 197.911058   | 20.674095   | SIO2V    | 1.56078570 | 90.000    |
| 3       | 635.116021   | 2.894278    |          | 1.00029966 | 90.000    |
| 4       | 154.515346   | 52.818599   | SIO2V    | 1.56078570 | 95.000    |
| 5       | -674.545898  | 46.213532   |          | 1.00029966 | 95.000    |
| 6       | 351.508267   | 12.006164   | SIO2V    | 1.56078570 | 76.354    |
| 7       | -355.431508  | 1.879459    |          | 1.00029966 | 73.677    |
| 8       | 137.853261   | 42.368303   | SIO2V    | 1.56078570 | 75.000    |
| 9       | -168.451126  | 1.576637    |          | 1.00029966 | 75.000    |
| 10      | $\infty$     | 18.000000   |          | 1.00029966 | 36.370    |
| 11      | $\infty$     | 10.000000   | SIO2V    | 1.56078570 | 44.778    |
| 12      | $\infty$     | 25.245183   |          | 1.00029966 | 47.596    |
| 13      | -69.535170   | 15.000107   | SIO2V    | 1.56078570 | 50.000    |
| 14      | -125.326320  | 1.000069    |          | 1.00029966 | 60.000    |
| 15      | -178.873389  | 25.788410   | SIO2V    | 1.56078570 | 65.000    |
| 16      | -101.720844  | 15.664259   |          | 1.00029966 | 70.000    |
| 17      | -199.223616  | 36.639577   | SIO2V    | 1.56078570 | 80.000    |
| 18      | -102.251112  | 0.099749    |          | 1.00029966 | 80.000    |
| 19      | $\infty$     | 40.000000   |          | 1.00029966 | 90.389    |
| 20      | $\infty$     | 209.622700  |          | 1.00029966 | 92.498    |
| 21      | -166.119896  | -209.622700 | REFL     | 1.00029966 | 150.000   |
| 22      | 175.984040   | 209.622700  | REFL     | 1.00029966 | 125.000   |
| 23      | $\infty$     | 40.000000   |          | 1.00029966 | 99.138    |
| 24      | $\infty$     | 0.172730    |          | 1.00029966 | 105.283   |
| 25      | 253.724164   | 38.159409   | SIO2V    | 1.56078570 | 110.000   |
| 26      | -576.959427  | 1.129890    |          | 1.00029966 | 110.000   |
| 27      | 969.471804   | 12.758546   | SIO2V    | 1.56078570 | 105.000   |
| 28      | 349.602989   | 0.999948    |          | 1.00029966 | 105.000   |
| 29      | 528.180407   | 10.000000   | SIO2V    | 1.56078570 | 95.000    |
| 30      | 121.034243   | 37.709281   |          | 1.00029966 | 80.000    |
| 31      | -511.453381  | 10.000000   | SIO2V    | 1.56078570 | 80.000    |
| 32      | 144.865830   | 27.748574   |          | 1.00029966 | 80.000    |
| 33      | -2683.436282 | 10.000000   | SIO2V    | 1.56078570 | 90.000    |
| 34      | 350.818886   | 21.231421   |          | 1.00029966 | 90.000    |
| 35      | 564.353180   | 43.838798   | SIO2V    | 1.56078570 | 120.000   |
| 36      | -231.828235  | 17.071926   |          | 1.00029966 | 120.000   |
| 37      | -844.682254  | 27.174378   | SIO2V    | 1.56078570 | 130.000   |
| 38      | -257.084208  | 13.572085   |          | 1.00029966 | 135.000   |
| 39      | -347.360290  | 79.971864   | SIO2V    | 1.56078570 | 140.000   |
| 40      | -191.420105  | 1.000000    |          | 1.00029966 | 155.000   |
| 41      | 638.593875   | 53.484057   | SIO2V    | 1.56078570 | 160.000   |
| 42      | -617.708478  | 0.999739    |          | 1.00029966 | 160.000   |
| 43      | 290.550562   | 51.321670   | SIO2V    | 1.56078570 | 150.000   |
| 44      | -1239.997337 | 1.000000    |          | 1.00029966 | 150.000   |
| 45      | 234.055441   | 41.191419   | SIO2V    | 1.56078570 | 125.000   |
| 46      | 1260.796700  | 1.000000    |          | 1.00029966 | 125.000   |
| 47      | 119.116897   | 46.087832   | SIO2V    | 1.56078570 | 92.000    |
| 48      | 410.714306   | 0.999596    |          | 1.00029966 | 90.000    |
| 49      | 57.007308    | 19.999880   | SIO2V    | 1.56078570 | 52.000    |
| 50      | 70.000000    | 24.719485   | (F)      | 1.65000000 | 48.000    |
| 51      | $\infty$     | 3.000000    | (F)      | 1.65000000 | 34.000    |
| 52 = IM | $\infty$     |             |          |            | 34.000    |

- 22 -

Table 2b

| ASPHERIC |               | CONSTANTS     |               |               |               |  |
|----------|---------------|---------------|---------------|---------------|---------------|--|
| SRF      | 2             | 5             | 7             | 15            | 17            |  |
| K        | 0             | 0             | 0             | 0             | 0             |  |
| C1       | -4.272071e-08 | -6.660852e-08 | 4.612425e-07  | -1.819217e-07 | -2.134272e-08 |  |
| C2       | -2.130756e-12 | 5.070507e-12  | 1.287676e-11  | -1.679339e-11 | 2.642130e-12  |  |
| C3       | -3.407494e-16 | -7.615346e-16 | 2.169742e-15  | -4.541462e-15 | 3.144530e-16  |  |
| C4       | 4.132704e-20  | 7.606615e-20  | 3.202709e-19  | 1.365731e-18  | -1.203833e-19 |  |
| C5       | -8.614408e-24 | 5.842474e-24  | 1.189789e-22  | -7.298537e-22 | 3.777303e-23  |  |
| C6       | 1.402057e-27  | -1.689387e-27 | -4.328782e-26 | 1.116111e-25  | -6.878338e-27 |  |
| C7       | -1.320281e-31 | 1.280496e-31  | 5.025746e-30  | 4.239480e-31  | 6.547727e-31  |  |
| C8       | 6.029685e-36  | -3.499149e-36 | -2.455352e-34 | -2.801453e-33 | -2.572158e-35 |  |
| SRF      | 21            | 22            | 28            | 36            | 37            |  |
| K        | -0.673243     | -0.223377     | 0             | 0             | 0             |  |
| C1       | 0.000000e+00  | 0.000000e+00  | -1.742865e-07 | -1.146354e-09 | -8.904146e-08 |  |
| C2       | -1.542990e-14 | 4.242474e-15  | 3.989651e-12  | 6.487508e-13  | -9.704035e-13 |  |
| C3       | -2.283008e-19 | -1.633115e-19 | 2.232371e-16  | 2.106572e-16  | 1.932349e-16  |  |
| C4       | -2.701974e-23 | 7.966751e-23  | -2.851297e-20 | -1.981895e-20 | -9.140962e-21 |  |
| C5       | 1.563798e-27  | -8.898817e-27 | 1.148424e-24  | 2.432642e-24  | 7.612481e-25  |  |
| C6       | -7.092827e-32 | 6.276885e-31  | 3.102982e-28  | -1.327579e-28 | -5.817189e-30 |  |
| C7       | 1.654890e-36  | -2.262895e-35 | -5.058499e-32 | 4.126250e-33  | -1.250231e-33 |  |
| C8       | -1.695530e-41 | 3.532661e-40  | 3.007511e-36  | -3.753435e-38 | 3.610689e-38  |  |
| SRF      | 39            | 43            | 46            |               |               |  |
| K        | 0             | 0             | 0             |               |               |  |
| C1       | 6.669745e-09  | -3.063876e-08 | -3.402805e-08 |               |               |  |
| C2       | 1.190421e-13  | 3.642882e-13  | 4.126635e-12  |               |               |  |
| C3       | -7.888065e-17 | 2.784805e-17  | -1.931151e-16 |               |               |  |
| C4       | -5.882168e-23 | -6.429270e-22 | 8.149530e-21  |               |               |  |
| C5       | 2.413262e-26  | 8.661549e-27  | -7.144438e-26 |               |               |  |
| C6       | 8.242901e-30  | -8.015685e-31 | -1.341671e-29 |               |               |  |
| C7       | -6.256631e-34 | 2.825051e-35  | 7.855498e-34  |               |               |  |
| C8       | 1.445073e-38  | -3.170258e-40 | -1.361588e-38 |               |               |  |

- 23 -

Table 3a

| SURF    | RADIUS        | THICKNESS   | MATERIAL  | INDEX      | SEMI DIAM. |
|---------|---------------|-------------|-----------|------------|------------|
| 0 = OB  | $\infty$      | 35.000000   |           | 1.00030168 | 66.000     |
| 1       | $\infty$      | 0.099980    |           | 1.00030168 | 77.003     |
| 2       | 170.078547    | 36.468596   | SIO2V     | 1.56078570 | 90.000     |
| 3       | -599.314872   | 2.182511    |           | 1.00029966 | 90.000     |
| 4       | 333.623154    | 49.026243   | SIO2V     | 1.56078570 | 95.000     |
| 5       | -5357.879827  | 17.783452   |           | 1.00029966 | 95.000     |
| 6       | 524.085081    | 39.656864   | SIO2V     | 1.56078570 | 76.354     |
| 7       | -372.985082   | 1.020916    |           | 1.00029966 | 73.677     |
| 8       | 273.494931    | 25.000000   | SIO2V     | 1.56078570 | 75.000     |
| 9       | -304.985535   | 1.000000    |           | 1.00029966 | 75.000     |
| 10      | 326.223899    | 32.555959   | SIO2V     | 1.56078570 | 75.000     |
| 11      | -194.836449   | 18.000006   |           | 1.00029966 | 75.000     |
| 12      | $\infty$      | 0.000000    |           | 1.00029966 | 36.370     |
| 13      | $\infty$      | 10.000000   | SIO2V     | 1.56078570 | 44.778     |
| 14      | $\infty$      | 24.420303   |           | 1.00029966 | 47.596     |
| 15      | -65.482398    | 15.000019   | SIO2V     | 1.56078570 | 50.000     |
| 16      | -89.830925    | 12.487606   |           | 1.00029966 | 60.000     |
| 17      | -181.375682   | 17.778805   | SIO2V     | 1.56078570 | 65.000     |
| 18      | -112.069227   | 1.008243    |           | 1.00029966 | 70.000     |
| 19      | -158.283947   | 37.090377   | SIO2V     | 1.56078570 | 80.000     |
| 20      | -102.436390   | 0.099969    |           | 1.00029966 | 80.000     |
| 21      | $\infty$      | 40.000000   |           | 1.00029966 | 90.389     |
| 22      | $\infty$      | 209.622700  |           | 1.00029966 | 92.498     |
| 23      | -166.136319   | -209.622700 | REFL      | 1.00029966 | 150.000    |
| 24      | 173.615104    | 209.622700  | REFL      | 1.00029966 | 125.000    |
| 25      | $\infty$      | 40.000000   |           | 1.00029966 | 99.138     |
| 26      | $\infty$      | 0.104935    |           | 1.00029966 | 105.283    |
| 27      | 161.705740    | 39.665166   | SIO2V     | 1.56078570 | 110.000    |
| 28      | 338.219127    | 4.220151    |           | 1.00029966 | 105.000    |
| 29      | 539.284856    | 10.000000   | SIO2V     | 1.56078570 | 95.000     |
| 30      | 115.279475    | 38.192763   |           | 1.00029966 | 80.000     |
| 31      | -713.073292   | 10.000000   | SIO2V     | 1.56078570 | 80.000     |
| 32      | 153.450259    | 25.766812   |           | 1.00029966 | 80.000     |
| 33      | -35457.805610 | 10.000000   | SIO2V     | 1.56078570 | 90.000     |
| 34      | 338.447211    | 22.577058   |           | 1.00029966 | 90.000     |
| 35      | 488.793543    | 45.370961   | SIO2V     | 1.56078570 | 120.000    |
| 36      | -229.090765   | 17.224093   |           | 1.00029966 | 120.000    |
| 37      | -813.380443   | 31.337371   | SIO2V     | 1.56078570 | 130.000    |
| 38      | -255.856356   | 9.074786    |           | 1.00029966 | 135.000    |
| 39      | -397.181958   | 81.335823   | SIO2V     | 1.56078570 | 140.000    |
| 40      | -197.104943   | 1.000000    |           | 1.00029966 | 155.000    |
| 41      | 616.283620    | 55.915659   | SIO2V     | 1.56078570 | 160.000    |
| 42      | -558.051853   | 0.999900    |           | 1.00029966 | 160.000    |
| 43      | 297.754439    | 48.959126   | SIO2V     | 1.56078570 | 150.000    |
| 44      | -1599.554010  | 1.000000    |           | 1.00029966 | 150.000    |
| 45      | 216.813876    | 43.986900   | SIO2V     | 1.56078570 | 125.000    |
| 46      | 2513.355923   | 1.000000    |           | 1.00029966 | 125.000    |
| 47      | 102.047705    | 42.326072   | SIO2V     | 1.56078570 | 88.000     |
| 48      | 258.213934    | 1.000000    |           | 1.00029966 | 85.000     |
| 49      | 67.045666     | 10.000000   | SIO2V     | 1.56078570 | 52.000     |
| 50      | 33.992537     | 27.639900   | (F)       | 1.65000000 | 33.000     |
| 51      | $\infty$      | 3.000000    |           | 1.80000000 | 33.000     |
| 52      | $\infty$      | 3.000000    | (IMMERS.) | 1.65000000 | 33.000     |
| 53 = IM | $\infty$      |             |           |            | 33.000     |

- 24 -

Table 3b

| ASPHERIC |               | CONSTANTS     |               |               |               |  |  |
|----------|---------------|---------------|---------------|---------------|---------------|--|--|
| SRF      | 2             | 5             | 7             | 17            | 19            |  |  |
| K        | 0             | 0             | 0             | 0             | 0             |  |  |
| C1       | -6.761238e-08 | -1.339952e-07 | 4.322957e-07  | -1.865717e-07 | 5.694739e-08  |  |  |
| C2       | -2.795074e-13 | 8.081896e-12  | 6.638487e-12  | -2.605817e-11 | 1.297663e-11  |  |  |
| C3       | -3.419978e-16 | -1.520519e-15 | 1.196137e-15  | -2.223425e-15 | 7.551094e-16  |  |  |
| C4       | 3.593975e-20  | 1.158356e-19  | 3.139076e-19  | 4.529397e-19  | -2.801640e-19 |  |  |
| C5       | -7.394770e-24 | 8.165985e-24  | -2.103438e-23 | -1.036163e-22 | -1.293839e-24 |  |  |
| C6       | 1.067458e-27  | -2.018394e-27 | -2.540248e-27 | -6.085859e-27 | 7.867948e-28  |  |  |
| C7       | -9.043542e-32 | 1.252003e-31  | 3.764879e-31  | 4.354732e-30  | 4.763906e-31  |  |  |
| C8       | 3.329797e-36  | -2.409824e-36 | -5.551249e-35 | -7.881442e-34 | -4.577122e-35 |  |  |
| SRF      | 23            | 24            | 28            | 36            | 37            |  |  |
| K        | -0.603427     | -0.236665     | 0             | 0             | 0             |  |  |
| C1       | 0.000000e+00  | 0.000000e+00  | -1.724255e-07 | 1.725752e-08  | -8.279489e-08 |  |  |
| C2       | -1.058224e-14 | 3.699741e-15  | 4.976445e-12  | 5.471441e-13  | -8.022210e-13 |  |  |
| C3       | -1.413269e-19 | -3.750775e-20 | 2.387092e-16  | 1.390990e-16  | 1.431148e-16  |  |  |
| C4       | -1.204112e-23 | 5.430640e-23  | 5.525729e-21  | -1.755950e-20 | -5.767930e-21 |  |  |
| C5       | 4.963866e-28  | -5.801174e-27 | -6.052665e-24 | 2.625696e-24  | 6.871766e-25  |  |  |
| C6       | -2.129066e-32 | 4.279164e-31  | 7.725095e-28  | -1.914617e-28 | -2.240962e-29 |  |  |
| C7       | 3.795477e-37  | -1.574698e-35 | -5.045738e-32 | 7.395971e-33  | -3.639715e-34 |  |  |
| C8       | -2.918284e-42 | 2.685481e-40  | 1.564423e-36  | -7.980691e-38 | 3.135529e-38  |  |  |
| SRF      | 39            | 43            | 46            |               |               |  |  |
| K        | 0             | 0             | 0             |               |               |  |  |
| C1       | 5.939680e-09  | -2.752287e-08 | -2.413171e-08 |               |               |  |  |
| C2       | -2.375134e-13 | 4.114456e-13  | 3.695674e-12  |               |               |  |  |
| C3       | -6.806224e-17 | 2.737675e-17  | -1.621470e-16 |               |               |  |  |
| C4       | -8.082613e-23 | -3.526372e-22 | 6.681382e-21  |               |               |  |  |
| C5       | -1.967221e-26 | -7.704679e-27 | -4.618168e-26 |               |               |  |  |
| C6       | 1.266402e-29  | -4.719101e-31 | -1.117841e-29 |               |               |  |  |
| C7       | -8.622711e-34 | 2.794633e-35  | 6.554350e-34  |               |               |  |  |
| C8       | 1.902299e-38  | -3.716332e-40 | -1.099816e-38 |               |               |  |  |

- 25 -

Table 4a

| SURF     | RADIUS        | THICKNESS   | MATERIAL | INDEX      | SEMI DIAM. |
|----------|---------------|-------------|----------|------------|------------|
| 0 = OB   | $\infty$      | 101.496840  |          |            | 62.000     |
| 1        | -523.184936   | 27.851984   | SIO2     | 1.56032610 | 96.419     |
| 2        | -210.066935   | 0.999968    |          |            | 99.916     |
| 3        | 143.399781    | 52.055602   | SIO2     | 1.56032610 | 115.102    |
| 4        | 345.776862    | 35.383042   |          |            | 110.966    |
| 5        | 168.075295    | 52.902563   | SIO2     | 1.56032610 | 95.593     |
| 6        | -581.011371   | 0.099991    |          |            | 85.017     |
| 7        | 82.494445     | 46.014670   | SIO2     | 1.56032610 | 65.623     |
| 8        | 74.608756     | 18.376623   |          |            | 43.366     |
| 9        | $\infty$      | 0.000000    | SIO2     | 1.56032610 | 40.333     |
| 10       | $\infty$      | 9.898700    |          |            | 40.333     |
| 11       | -93.661632    | 25.608969   | SIO2     | 1.56032610 | 40.388     |
| 12       | -97.944812    | 42.548618   |          |            | 50.610     |
| 13       | -63.503040    | 54.172316   | SIO2     | 1.56032610 | 58.454     |
| 14       | -94.409957    | 1.264244    |          |            | 87.595     |
| 15       | -328.877474   | 40.537580   | SIO2     | 1.56032610 | 104.907    |
| 16       | -131.896136   | 1.001643    |          |            | 106.846    |
| 17       | 204.370502    | 42.653441   | SIO2     | 1.56032610 | 107.596    |
| 18       | -2747.675446  | 1.723900    |          |            | 105.816    |
| 19       | 216.208053    | 27.952948   | SIO2     | 1.56032610 | 97.813     |
| 20       | 2712.784924   | 99.872557   |          |            | 94.335     |
| 21 = FM1 | $\infty$      | -160.545313 | REFL     |            | 27.154     |
| 22       | 101.244286    | -12.500000  | SIO2     | 1.56032610 | 72.986     |
| 23       | 628.850173    | -53.212241  |          |            | 88.277     |
| 24       | 102.805812    | -12.500000  | SIO2     | 1.56032610 | 91.193     |
| 25       | 200.305727    | -25.464217  |          |            | 119.887    |
| 26       | 150.933505    | 25.464217   | REFL     |            | 122.686    |
| 27       | 200.305727    | 12.500000   | SIO2     | 1.56032610 | 119.499    |
| 28       | 102.805812    | 53.212241   |          |            | 90.105     |
| 29       | 628.850173    | 12.500000   | SIO2     | 1.56032610 | 85.671     |
| 30       | 101.244286    | 160.545353  |          |            | 71.821     |
| 31 = FM2 | $\infty$      | -109.999623 | REFL     |            | 134.552    |
| 32       | 862.422907    | -30.130833  | SIO2     | 1.56032610 | 102.165    |
| 33       | 229.773890    | -0.999915   |          |            | 105.942    |
| 34       | -617.789022   | -35.509195  | SIO2     | 1.56032610 | 118.697    |
| 35       | 565.469461    | -0.999931   |          |            | 120.255    |
| 36       | -246.806971   | -44.859593  | SIO2     | 1.56032610 | 124.965    |
| 37       | 32400.831779  | -0.099930   |          |            | 123.417    |
| 38       | -158.610832   | -71.070427  | SIO2     | 1.56032610 | 112.458    |
| 39       | -1341.469728  | -8.796304   |          |            | 98.473     |
| 40       | 3541.685396   | -11.999956  | SIO2     | 1.56032610 | 96.987     |
| 41       | -126.167849   | -44.791303  |          |            | 78.038     |
| 42       | 469.858200    | -11.999957  | SIO2     | 1.56032610 | 78.204     |
| 43       | -108.758112   | -27.637030  |          |            | 84.487     |
| 44       | -1480.509587  | -15.438600  | SIO2     | 1.56032610 | 86.624     |
| 45       | 2433.499100   | -49.439954  |          |            | 90.710     |
| 46       | -1932.185692  | -25.660740  | SIO2     | 1.56032610 | 119.141    |
| 47       | 428.080551    | -0.999961   |          |            | 123.769    |
| 48       | -408.475637   | -36.662820  | SIO2     | 1.56032610 | 147.587    |
| 49       | -16389.465356 | -7.335981   |          |            | 148.838    |
| 50       | -342.428932   | -60.116835  | SIO2     | 1.56032610 | 158.305    |
| 51       | 658.847066    | -0.091541   |          |            | 157.731    |
| 52       | $\infty$      | 0.000000    | SIO2     | 1.56032610 | 156.315    |
| 53       | $\infty$      | -2.670708   |          |            | 156.315    |

- 26 -

Table 4a (cont.)

|         |             |            |      |            |         |
|---------|-------------|------------|------|------------|---------|
| 54      | -702.444090 | -32.792626 | SiO2 | 1.56032610 | 155.963 |
| 55      | 1222.808780 | -0.999915  |      |            | 155.470 |
| 56      | -309.712976 | -41.860232 | SiO2 | 1.56032610 | 144.999 |
| 57      | 3694.385507 | -0.999819  |      |            | 144.012 |
| 58      | -135.513673 | -31.965622 | SiO2 | 1.56032610 | 109.063 |
| 59      | -185.513505 | -0.999775  |      |            | 103.967 |
| 60      | -88.090936  | -38.540831 | SiO2 | 1.56032610 | 80.707  |
| 61      | -187.712668 | -0.999577  |      |            | 73.736  |
| 62      | -58.692832  | -9.999803  | SiO2 | 1.56032610 | 51.770  |
| 63      | -33.167937  | -38.114503 | (F)  | 1.65000000 | 33.117  |
| 64      | $\infty$    | -3.000000  | (F)  | 1.65000000 | 20.048  |
| 65 = IM | $\infty$    |            |      |            | 15.841  |

- 27 -

Table 4b

| ASPHERIC |               | CONSTANTS     |               |               |               |  |  |
|----------|---------------|---------------|---------------|---------------|---------------|--|--|
| SRF      | 6             | 15            | 20            | 22            | 30            |  |  |
| K        | 0             | 0             | 0             | 0             | 0             |  |  |
| C1       | 1.190289e-07  | -1.976769e-08 | 4.403358e-08  | -6.572731e-08 | -6.572731e-08 |  |  |
| C2       | -2.160947e-12 | 1.109889e-12  | 8.071972e-17  | -4.743844e-12 | -4.743844e-12 |  |  |
| C3       | 6.852608e-16  | -3.889116e-17 | 3.366541e-18  | -9.012440e-18 | -9.012440e-18 |  |  |
| C4       | -3.837379e-20 | -1.882901e-21 | 5.100729e-22  | -1.597994e-19 | -1.597994e-19 |  |  |
| C5       | 1.217764e-25  | 1.332477e-25  | -4.259657e-26 | 2.141145e-23  | 2.141145e-23  |  |  |
| C6       | 2.211313e-28  | -2.258521e-30 | 2.686157e-30  | -2.250289e-27 | -2.250289e-27 |  |  |
|          |               |               |               |               |               |  |  |
| SRF      | 39            | 41            | 43            | 46            | 51            |  |  |
| K        | 0             | 0             | 0             | 0             | 0             |  |  |
| C1       | 1.699431e-08  | -2.143897e-07 | 2.168103e-07  | 3.156834e-08  | -7.013045e-09 |  |  |
| C2       | -9.046901e-12 | 2.732198e-12  | 1.367067e-12  | 3.487654e-13  | 5.963914e-16  |  |  |
| C3       | 1.128480e-15  | -1.371285e-15 | 3.062347e-16  | -1.560492e-17 | -1.630073e-17 |  |  |
| C4       | -9.595855e-20 | -1.137997e-19 | 5.350290e-20  | 1.140928e-21  | 5.396066e-22  |  |  |
| C5       | 5.011204e-24  | 2.693954e-23  | -4.811379e-24 | -4.815997e-26 | -7.602819e-27 |  |  |
| C6       | -1.196219e-28 | -3.312568e-27 | 4.970104e-28  | 5.836063e-31  | 4.085943e-32  |  |  |
|          |               |               |               |               |               |  |  |
| SRF      | 59            | 61            |               |               |               |  |  |
| K        | 0             | 0             |               |               |               |  |  |
| C1       | 4.429013e-08  | -9.119846e-08 |               |               |               |  |  |
| C2       | -4.664097e-12 | -9.933832e-12 |               |               |               |  |  |
| C3       | 3.978191e-16  | 4.577490e-16  |               |               |               |  |  |
| C4       | -1.307434e-20 | -2.618132e-19 |               |               |               |  |  |
| C5       | -5.651715e-25 | 5.019446e-23  |               |               |               |  |  |
| C6       | 3.529575e-29  | -5.414482e-27 |               |               |               |  |  |

- 28 -

Table 5a

| SURF    | RADIUS       | THICKNESS   | MATERIAL | INDEX      | SEMIDIAM. |
|---------|--------------|-------------|----------|------------|-----------|
| 0 = OB  | $\infty$     | 31.284792   |          |            | 52.000    |
| 1       | 194.413567   | 32.720399   | SIO2V    | 1.56078570 | 74.615    |
| 2       | -837.875926  | 6.370734    |          |            | 74.349    |
| 3       | 95.475130    | 26.728836   | SIO2V    | 1.56078570 | 70.388    |
| 4       | 148.726918   | 30.489652   |          |            | 65.856    |
| 5       | 1084.901978  | 14.117445   | SIO2V    | 1.56078570 | 60.419    |
| 6       | -329.264238  | 0.743287    |          |            | 58.910    |
| 7       | 372.368293   | 15.458004   | SIO2V    | 1.56078570 | 54.832    |
| 8       | -148.979042  | 27.240305   |          |            | 52.113    |
| 9       | $\infty$     | 32.301644   |          |            | 43.951    |
| 10      | -57.723183   | 31.449460   | SIO2V    | 1.56078570 | 47.695    |
| 11      | -71.150453   | 0.929754    |          |            | 62.740    |
| 12      | 383.639393   | 22.046149   | SIO2V    | 1.56078570 | 83.185    |
| 13      | -904.695268  | 0.905975    |          |            | 84.675    |
| 14      | 179.698033   | 38.448563   | SIO2V    | 1.56078570 | 90.818    |
| 15      | -389.247961  | 29.862111   |          |            | 90.050    |
| 16      | $\infty$     | 258.234067  |          |            | 85.109    |
| 17      | -151.387947  | -258.234067 | REFL     |            | 103.744   |
| 18      | 258.267631   | 258.234067  | REFL     |            | 180.342   |
| 19      | $\infty$     | 29.981280   |          |            | 116.992   |
| 20      | 251.052546   | 31.241091   | SIO2V    | 1.56078570 | 101.576   |
| 21      | -6016.827917 | 77.406555   |          |            | 98.554    |
| 22      | -125.618112  | 8.960662    | SIO2V    | 1.56078570 | 70.289    |
| 23      | 129.125754   | 28.406854   |          |            | 68.882    |
| 24      | -681.780853  | 8.898731    | SIO2V    | 1.56078570 | 70.634    |
| 25      | 205.568565   | 41.577461   |          |            | 78.503    |
| 26      | -183.215344  | 15.843375   | SIO2V    | 1.56078570 | 82.563    |
| 27      | -747.008350  | 6.201177    |          |            | 102.654   |
| 28      | 1186.195936  | 72.658205   | SIO2V    | 1.56078570 | 120.160   |
| 29      | -156.971444  | 0.905847    |          |            | 126.492   |
| 30      | 648.451941   | 66.013805   | SIO2V    | 1.56078570 | 163.810   |
| 31      | -396.824326  | 25.988117   |          |            | 165.175   |
| 32      | 289.870283   | 40.412480   | SIO2V    | 1.56078570 | 163.677   |
| 33      | 480.887470   | 0.928925    |          |            | 161.538   |
| 34      | 178.362272   | 40.967739   | SIO2V    | 1.56078570 | 144.125   |
| 35      | 253.519298   | 0.947294    |          |            | 138.643   |
| 36      | 154.855021   | 52.211656   | SIO2V    | 1.56078570 | 125.560   |
| 37      | 522.613285   | 0.825571    |          |            | 119.129   |
| 38      | 100.582695   | 44.936735   | SIO2V    | 1.56078570 | 88.620    |
| 39      | 272.608820   | 0.825571    |          |            | 79.210    |
| 40      | 58.829925    | 8.861393    | SIO2V    | 1.56078570 | 52.876    |
| 41      | 37.856352    | 45.769132   | (F)      | 1.80000000 | 37.564    |
| 42 = IM | $\infty$     |             |          |            | 13.001    |

- 29 -

Table 5b

| ASPHERIC |               | CONSTANTS     |               |               |               |  |
|----------|---------------|---------------|---------------|---------------|---------------|--|
| SRF      | 1             | 5             | 8             | 15            | 17            |  |
| K        | 0             | 0             | 0             | 0             | 0             |  |
| C1       | 2.035368e-07  | 1.161173e-07  | 6.549025e-07  | 1.058964e-07  | 1.486128e-08  |  |
| C2       | 2.122045e-13  | -9.174854e-11 | 1.133907e-11  | -1.960464e-12 | 6.224903e-13  |  |
| C3       | -1.232124e-15 | 9.078126e-15  | 2.931708e-14  | -1.719346e-16 | 1.675590e-17  |  |
| C4       | 6.485869e-20  | -1.260952e-18 | -8.285156e-18 | 2.217335e-20  | 1.269177e-21  |  |
| C5       | 9.917577e-24  | 2.019305e-22  | 3.500031e-21  | -1.159319e-24 | -5.260128e-26 |  |
| C6       | -9.582163e-28 | -7.811919e-27 | 3.522430e-26  | 2.527662e-29  | 4.654328e-30  |  |
| SRF      | 18            | 22            | 25            | 28            | 33            |  |
| K        | -0.267731     | 0             | 0             | 0             | 0             |  |
| C1       | -7.023674e-10 | 4.605486e-07  | 2.881794e-07  | -3.576109e-08 | -1.085274e-08 |  |
| C2       | -9.477643e-15 | -7.227058e-11 | -4.494181e-11 | 8.140963e-13  | 1.115172e-13  |  |
| C3       | -7.423466e-20 | 1.056869e-14  | -2.448411e-15 | -3.935804e-17 | -9.843842e-18 |  |
| C4       | -4.429195e-24 | -1.243813e-18 | 9.621332e-19  | -7.624420e-22 | -1.420093e-22 |  |
| C5       | 4.705745e-29  | 1.098424e-22  | -9.474976e-23 | 1.473104e-25  | 1.350399e-26  |  |
| C6       | -1.008977e-33 | -3.554283e-27 | 3.735014e-27  | -5.284140e-30 | -1.682167e-31 |  |
| SRF      | 37            | 39            |               |               |               |  |
| K        | 0             | 0             |               |               |               |  |
| C1       | 2.842058e-08  | 1.106769e-07  |               |               |               |  |
| C2       | -9.189727e-15 | 2.940296e-12  |               |               |               |  |
| C3       | 7.067187e-17  | -8.536341e-17 |               |               |               |  |
| C4       | -5.862923e-21 | 4.590349e-20  |               |               |               |  |
| C5       | 2.902121e-25  | -8.754730e-24 |               |               |               |  |
| C6       | -4.976330e-30 | 5.665333e-28  |               |               |               |  |

- 30 -

Table 6a

| SURF    | RADIUS       | THICKNESS   | MATERIAL  | INDEX      | SEMI DIAM. |
|---------|--------------|-------------|-----------|------------|------------|
| 0 = OB  | $\infty$     | 31.284792   |           |            | 52.000     |
| 1       | $\infty$     | 0.000000    |           |            | 65.651     |
| 2       | 193.599182   | 32.235664   | SIO2V     | 1.56078570 | 74.583     |
| 3       | -988.153919  | 6.121005    |           |            | 74.317     |
| 4       | 95.312730    | 28.437060   | SIO2V     | 1.56078570 | 70.720     |
| 5       | 149.958061   | 29.337945   |           |            | 65.762     |
| 6       | 990.600274   | 14.692793   | SIO2V     | 1.56078570 | 60.664     |
| 7       | -304.549723  | 0.925424    |           |            | 59.160     |
| 8       | 405.862783   | 15.231330   | SIO2V     | 1.56078570 | 54.862     |
| 9       | -150.695673  | 27.371286   |           |            | 52.107     |
| 10      | $\infty$     | 32.082969   |           |            | 43.913     |
| 11      | -57.761263   | 34.954745   | SIO2V     | 1.56078570 | 47.628     |
| 12      | -73.049428   | 0.946034    |           |            | 64.468     |
| 13      | 371.078196   | 22.631363   | SIO2V     | 1.56078570 | 85.710     |
| 14      | -1054.171246 | 2.527973    |           |            | 87.142     |
| 15      | 176.905790   | 40.262309   | SIO2V     | 1.56078570 | 93.860     |
| 16      | -409.710820  | 29.670881   |           |            | 92.937     |
| 17      | $\infty$     | 262.083723  |           |            | 87.656     |
| 18      | -152.961072  | -262.083723 | REFL      |            | 102.730    |
| 19      | 259.893027   | 262.083723  | REFL      |            | 180.288    |
| 20      | $\infty$     | 40.275992   |           |            | 112.284    |
| 21      | 277.112135   | 28.048210   | SIO2V     | 1.56078570 | 94.722     |
| 22      | -1786.674721 | 65.923060   |           |            | 91.958     |
| 23      | -115.766876  | 9.003310    | SIO2V     | 1.56078570 | 70.538     |
| 24      | 143.904953   | 28.199458   |           |            | 69.827     |
| 25      | -500.404643  | 8.993973    | SIO2V     | 1.56078570 | 71.476     |
| 26      | 231.435891   | 40.923491   |           |            | 79.540     |
| 27      | -194.421161  | 14.041869   | SIO2V     | 1.56078570 | 83.835     |
| 28      | -929.354406  | 6.572149    |           |            | 102.684    |
| 29      | 1551.636561  | 74.150055   | SIO2V     | 1.56078570 | 118.556    |
| 30      | -151.390217  | 0.924156    |           |            | 124.858    |
| 31      | 430.573439   | 62.728287   | SIO2V     | 1.56078570 | 165.041    |
| 32      | -668.844997  | 23.423849   |           |            | 165.694    |
| 33      | 303.567518   | 38.823785   | SIO2V     | 1.56078570 | 163.062    |
| 34      | 524.212908   | 0.932060    |           |            | 160.960    |
| 35      | 176.353964   | 40.731123   | SIO2V     | 1.56078570 | 143.422    |
| 36      | 247.491117   | 0.936510    |           |            | 137.926    |
| 37      | 153.122143   | 51.077607   | SIO2V     | 1.56078570 | 124.946    |
| 38      | 412.041144   | 0.825571    |           |            | 118.371    |
| 39      | 101.547710   | 45.611823   | SIO2V     | 1.56078570 | 89.393     |
| 40      | 315.478434   | 0.825571    |           |            | 80.057     |
| 41      | 58.429322    | 8.969645    | SIO2V     | 1.56078570 | 53.083     |
| 42      | 38.144755    | 40.197998   | (F)       | 1.80000000 | 37.922     |
| 43      | $\infty$     | 3.000000    | SAPHIR    | 1.92650829 | 25.925     |
| 44      | $\infty$     | 4.345594    | (IMMERS.) | 1.80000000 | 21.446     |
| 45 = IM | $\infty$     |             |           |            | 13.000     |

- 31 -

Table 6b

| ASPHERIC |               | CONSTANTS     |               |               |               |  |
|----------|---------------|---------------|---------------|---------------|---------------|--|
| SRF      | 2             | 6             | 9             | 16            | 18            |  |
| K        | 0             | 0             | 0             | 0             | 0             |  |
| C1       | 1.958847e-07  | 1.048404e-07  | 6.380918e-07  | 1.042335e-07  | 1.494444e-08  |  |
| C2       | 8.684629e-13  | -9.344654e-11 | 1.135337e-11  | -1.647926e-12 | 6.329335e-13  |  |
| C3       | -1.177298e-15 | 9.684195e-15  | 2.969291e-14  | -1.770077e-16 | 1.568829e-17  |  |
| C4       | 5.172091e-20  | -1.242151e-18 | -8.230472e-18 | 1.938739e-20  | 1.153993e-21  |  |
| C5       | 1.115087e-23  | 1.848517e-22  | 3.507973e-21  | -8.862178e-25 | -3.871456e-26 |  |
| C6       | -9.813899e-28 | -8.222149e-27 | 3.205808e-26  | 1.726247e-29  | 3.672792e-30  |  |
| SRF      | 19            | 23            | 26            | 29            | 34            |  |
| K        | -0.273225     | 0             | 0             | 0             | 0             |  |
| C1       | -4.825071e-10 | 5.116169e-07  | 3.252068e-07  | -2.515552e-08 | -1.130904e-08 |  |
| C2       | -6.621967e-15 | -7.631783e-11 | -4.649504e-11 | 1.947845e-13  | 2.463683e-13  |  |
| C3       | -6.600515e-20 | 1.115383e-14  | -2.574578e-15 | -1.814191e-17 | -1.101814e-17 |  |
| C4       | -4.043335e-24 | -1.308686e-18 | 1.022883e-18  | -1.328934e-21 | -2.972090e-22 |  |
| C5       | 4.835743e-29  | 1.177910e-22  | -9.907368e-23 | 1.639600e-25  | 1.942591e-26  |  |
| C6       | -1.092461e-33 | -3.908759e-27 | 3.745941e-27  | -5.808419e-30 | -2.321607e-31 |  |
| SRF      | 38            | 40            |               |               |               |  |
| K        | 0             | 0             |               |               |               |  |
| C1       | 2.336279e-08  | 1.464967e-07  |               |               |               |  |
| C2       | -1.224680e-12 | 1.974044e-12  |               |               |               |  |
| C3       | 1.869425e-16  | -4.637058e-16 |               |               |               |  |
| C4       | -1.001651e-20 | 1.216769e-19  |               |               |               |  |
| C5       | 3.399061e-25  | -1.544405e-23 |               |               |               |  |
| C6       | -4.264065e-30 | 7.169909e-28  |               |               |               |  |

- 32 -

## Claims:

1. Objective designed as a microlithography projection objective for an operating wavelength,
  - having a greatest adjustable image-side numerical aperture NA,
  - 5 - having at least one first lens made from a solid transparent body, in particular glass or crystal, with a refractive index  $n_L$ ,
  - having at least one liquid lens (F) made from a transparent liquid, with a refractive index  $n_F$ ,
  - 10 wherein at the operating wavelength
    - the first lens has the greatest refractive index  $n_L$  of all solid lenses of the objective,
    - the refractive index  $n_F$  of the at least one liquid lens (F) is bigger than the refractive index  $n_L$  of the first lens
    - 15 - and the value of the numerical aperture NA is bigger than 1.
- 20 2. Objective according to Claim 1, characterized in that at the operating wavelength the refractive indices  $n_F$  and  $n_L$  and the numerical aperture NA are related to each other according to  $n_F > NA > n_L$ .
- 25 3. Objective according to at least one of the preceding claims, characterized in that at the operating wavelength the numerical aperture  $NA \geq 1.4$ .
4. Objective according to at least one of the preceding claims, characterized in that the at least one liquid lens (F) is the last curved optical element on the image side.
- 30

- 33 -

5. Objective according to at least one of the preceding claims, characterized in that a plane-parallel plate (EP) is arranged between the at least one liquid lens (F) and the image plane (IM) of the objective.

6. Objective according to Claim 5, characterized in that at the operating wavelength the refractive index  $n_{EP}$  of the plane-parallel plate (EP) is greater than the refractive index  $n_F$  of the at least one liquid lens (F), in particular in that the plane-parallel plate consists of sapphire.

7. Objective according to at least one of the preceding claims, characterized in that the at least one liquid lens (F) is essentially hemispherical and, in particular, has a thickness on the optical axis of the objective that is 80 to 110% of the radius of its curved surface.

8. Objective according to at least one of the preceding claims, characterized in that it exhibits one or two intermediate images (IM1, IM2).

9. Objective according to at least one of the preceding claims, characterized in that it is catadioptric.

10. Objective according to at least one of the preceding claims, characterized in that it comprises an image-side objective part arranged at the image-side end of the objective and being refractive.

- 34 -

11. Objective according to Claim 10, characterized in that the pupil (P) of the image-side objective part is arranged between a lens at which the traversing light  
5 bundle is of greatest diameter and the image plane (IM).

12. Objective according to at least one of the preceding claims, characterized in that a number of  
10 meniscus lenses of positive refractive power, which have a concave shape on the image side, are preceding the at least one liquid lens (F).

13. Objective according to at least one of the preceding claims, characterized in that a stop-down  
15 system aperture is arranged in an object-side objective part, which is located at the object-side end of the objective.

20 14. Objective according to at least one of the preceding claims, characterized in that at the operating wavelength the refractive index  $n_F$  of the at least one liquid lens (F) is bigger than 1.4, preferably equal to or bigger than 1.6.

25 15. Objective according to at least one of the preceding claims, characterized in that it is a catadioptric objective for which all refracting or reflecting surfaces are rotationally symmetrical in  
30 relation to a common axis.

- 35 -

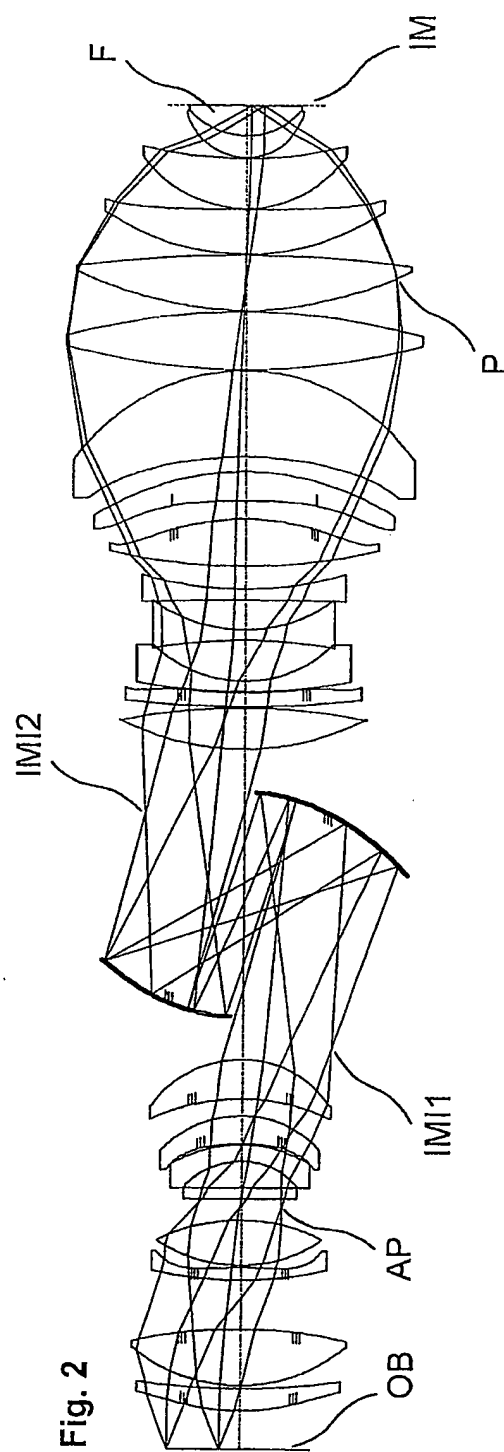
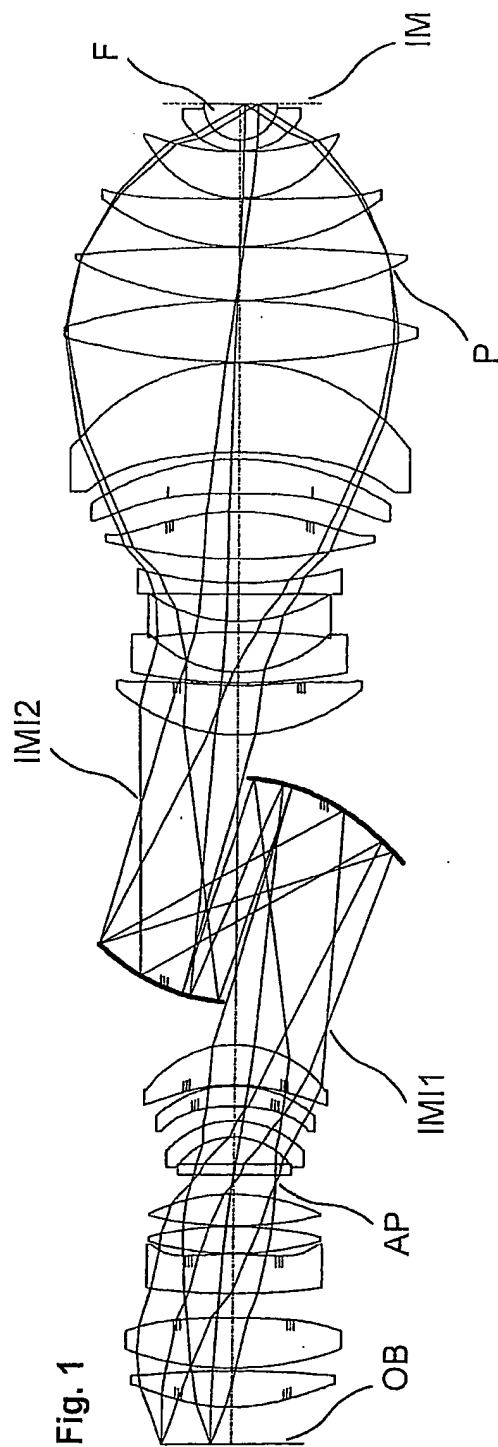
16. Objective according to at least one of the preceding claims, characterized in that it is a catadioptric objective and all the mirrors are curved.
- 5 17. Objective according to at least one of the preceding claims, characterized in that it comprises a catoptric or catadioptric objective part.
- 10 18. Objective according to at least one of the preceding claims, characterized in that it comprises a catadioptric objective part with a concave mirror and a negative lens.
- 15 19. Objective according to at least one of the preceding claims, characterized in that it is an immersion objective.
- 20 20. Objective according to at least one of the preceding claims, characterized in that at least one liquid lens (F) touches the image plane (IM) and an object, if the object is arranged in the image plane in order to be exposed.
- 25 21. Objective according to at least one of the preceding claims, characterized in that it includes an object-side last element made from a transparent solid body, in particular a plane-parallel plate (EP) according to Claim 5 or 6, and in that a transparent medium with a refractive index  $n_r > 1.1$  at the operating  
30 wavelength is arranged between this element and an object in the region of the image plane (IM).

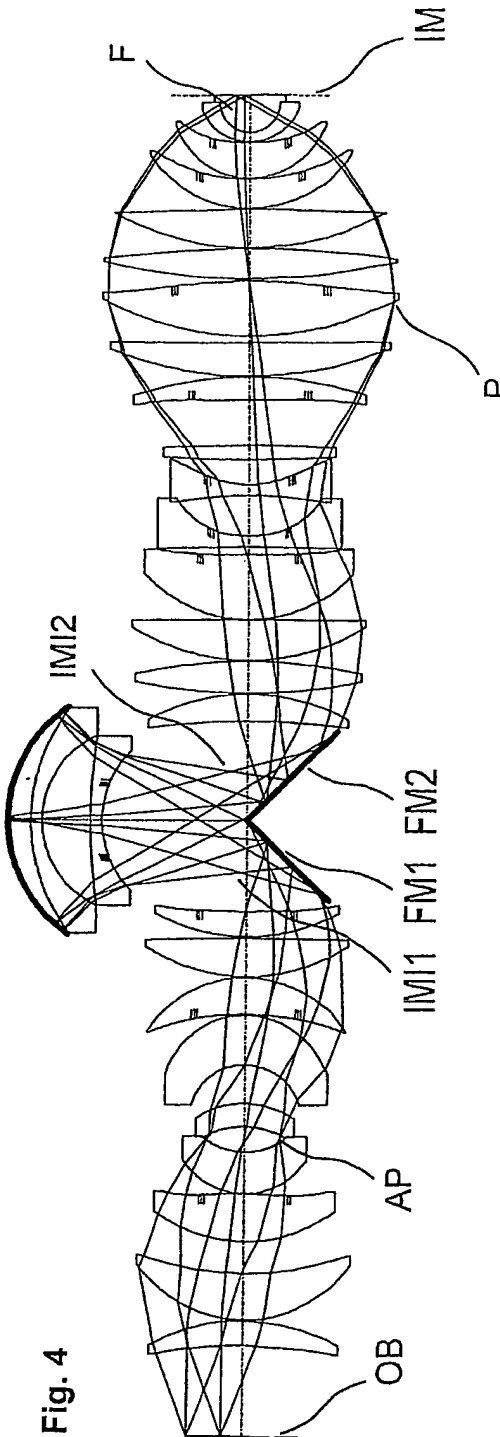
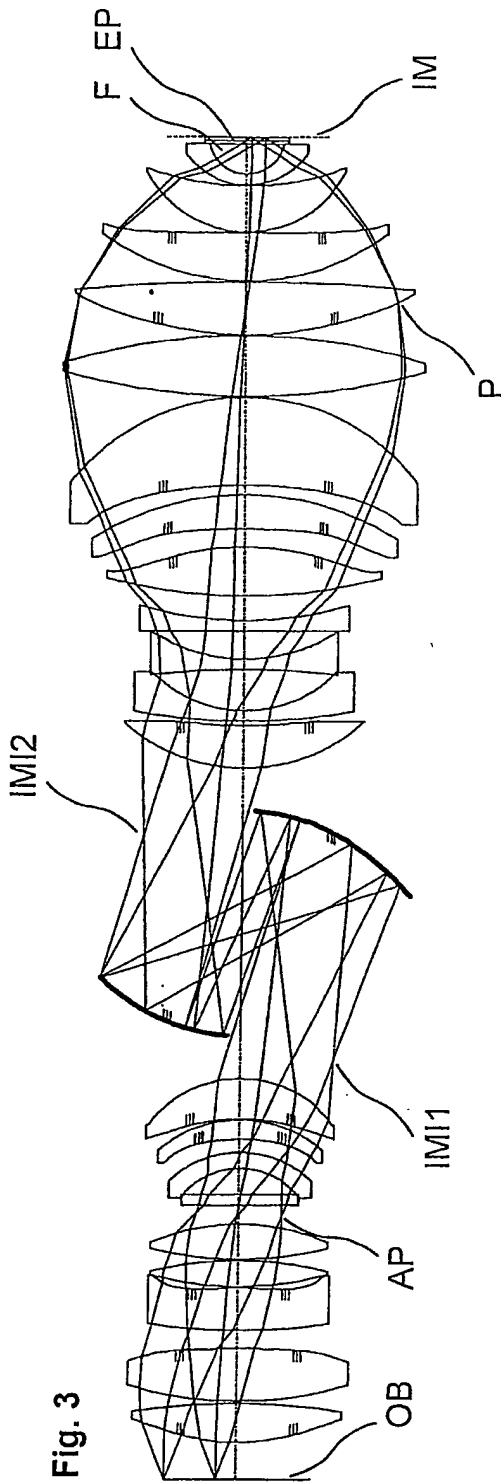
- 36 -

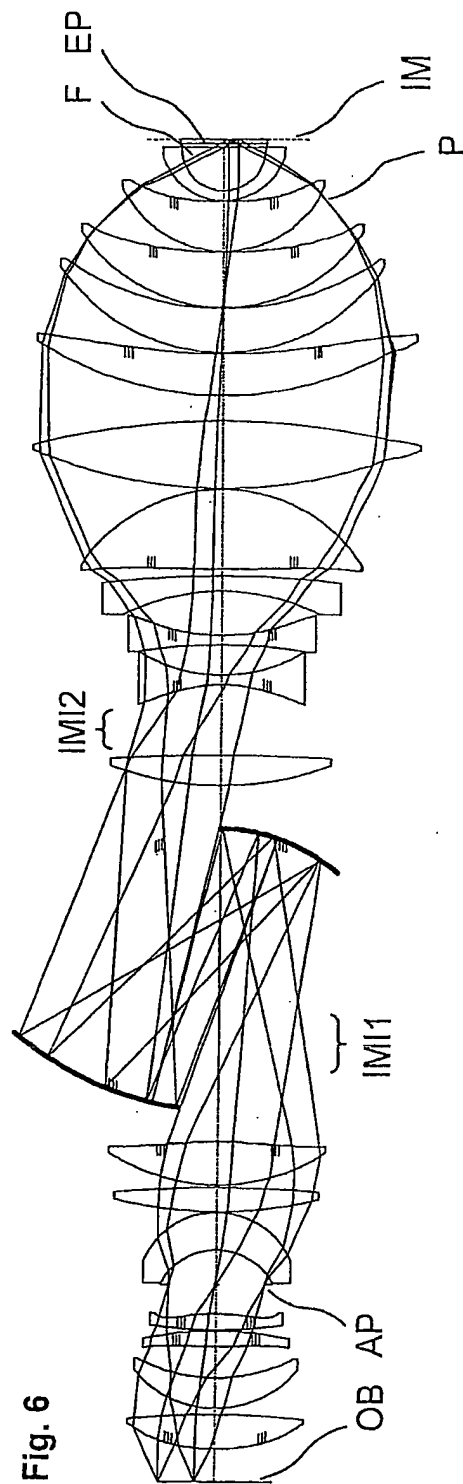
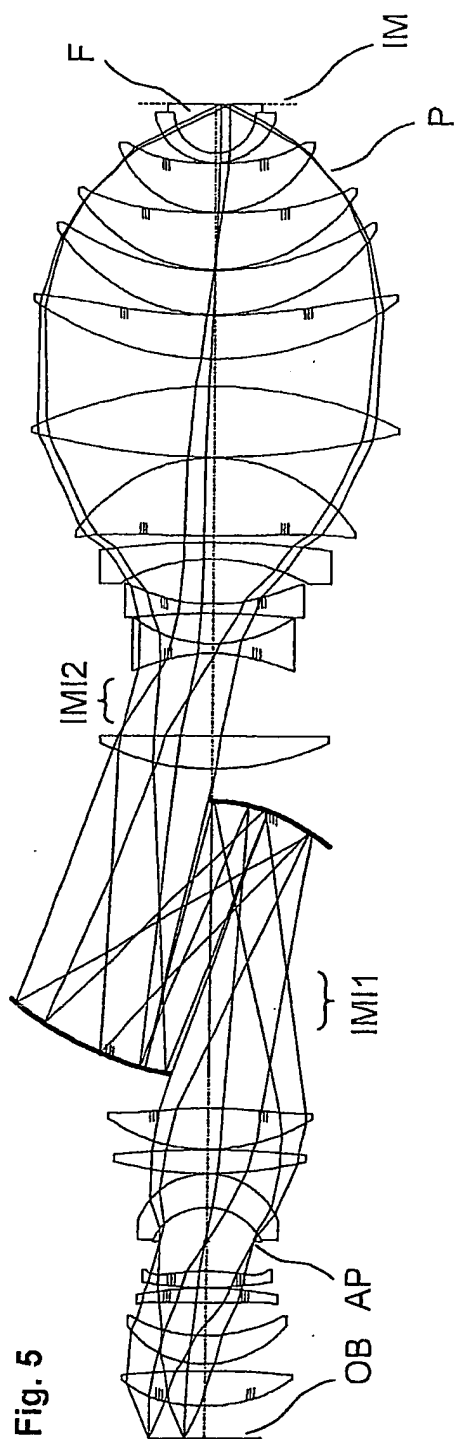
22. Objective according to Claim 21, characterized in that at the operating wavelength it holds that  $n_I = n_F$ .

23. Objective according to Claim 21 or Claim 22,  
5 characterized in that at the operating wavelength it holds that  $n_I \geq n_L$ .

24. Objective according to at least one of the preceding claims, characterized in that a material of  
10 the first lens or further lenses is a material from the group of fused silica and fluoride monocrystals comprising  $\text{CaF}_2$ ,  $\text{BaF}_2$ ,  $\text{SrF}_2$ ,  $\text{LiF}$ ,  $\text{NaF}$ .







## INTERNATIONAL SEARCH REPORT

International Application No.

PCT/EP2004/014219

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 G03F7/20

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G03F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages  | Relevant to claim No. |
|------------|---|-----------------------|
| A          | US 2003/174408 A1 (ROSTALSKI HANS-JUERGEN ET AL) 18 September 2003 (2003-09-18) paragraphs '0025!', '0057!'; table 1  | 1-24                  |
| A          | HOFFNAGLE J A ET AL: "Liquid immersion deep-ultraviolet interferometric lithography"<br>JOURNAL OF VACUUM SCIENCE & TECHNOLOGY B: MICROELECTRONICS PROCESSING AND PHENOMENA, AMERICAN VACUUM SOCIETY, NEW YORK, NY, US, vol. 17, no. 6, November 1999 (1999-11), pages 3306-3309, XP012007924<br>ISSN: 0734-211X<br>page 3307 - page 3308<br>NA=1.2, $n(\text{prism}) = 1.5 < n(\text{immersion}) = 1.51$<br>-----<br>-/- | 1                     |

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex

## \* Special categories of cited documents:

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the international filing date
- \*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

- \*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- \*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- \*Y\* document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- \*&\* document member of the same patent family

Date of the actual completion of the international search

25 May 2005

Date of mailing of the international search report

10/06/2005

Name and mailing address of the ISA

European Patent Office, P.B. 5618 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx 31 651 epo nl,  
Fax (+31-70) 340-3016

Authorized officer

Eisner, K

## INTERNATIONAL SEARCH REPORT

International Application No

PCT/EP2004/014219

| C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT |   |                      |
|--|---|----------------------|
| Category *   | Citation of document, with indication, where appropriate, of the relevant passages  | Relevant to claim No |
| P,X  | <p>BRUCE SMITH: "Water-based 193nm immersion lithography" 'Online!<br/>28 January 2004 (2004-01-28), XP002329291<br/>Retrieved from the Internet:<br/>URL: <a href="http://www.sematech.org/resources/litho/meetings/immersion/20040128/presentations/06%20RIT%20microstepper%20efforts_Smith.pdf">http://www.sematech.org/resources/litho/meetings/immersion/20040128/presentations/06%20RIT%20microstepper%20efforts_Smith.pdf</a><br/>&gt; 'retrieved on 2005-05-24!<br/>page 14: NA &gt; 1, lens material: SiO<sub>2</sub><br/>page 22: n(liquid lens) &gt; 1.6 &gt; n(SiO<sub>2</sub>)<br/>-----</p> | 1-24                 |

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/EP2004/014219

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
|---|---------------------|----------------------------|---------------------|
| US 2003174408 A1                          | 18-09-2003          | DE 10210899 A1             | 18-09-2003          |
|   |                     | AU 2002312872 A1           | 22-09-2003          |
|   |                     | AU 2003221490 A1           | 22-09-2003          |
|   |                     | WO 03077036 A1             | 18-09-2003          |
|   |                     | WO 03077037 A1             | 18-09-2003          |
|   |                     | EP 1483625 A1              | 08-12-2004          |
|   |                     | EP 1485760 A1              | 15-12-2004          |
|   |                     | US 2005030506 A1           | 10-02-2005          |
| -----                                     |                     |                            |                     |